Optimal Control of Brucellosis in Bison in the Yellowstone National Park Area

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Introduction

Wildlife disease management is growing in attention, as wildlife populations increasingly serve as disease reservoirs for encroaching human or livestock populations. In addition, some diseases have been implicated in extinctions and near-extinctions of many wildlife species (Tompkins and Wilson, 1998). The focus in disease ecology has been on disease dynamics in the absence of human impacts, while there has been relatively little research in the area of the economics of disease control among wildlife populations. Therefore, wildlife disease management has become a challenge to integrate biological and human dimensions for improved wildlife management.

Brucellosis in bison in the Yellowstone National Park (YNP)

- Brucellosis is a bacterial disease that causes bison and cattle to abort their calves. It has caused devastating losses to farmers over the last century. The only known focus of *Brucella abortus* infection left in the nation is in the Greater Yellowstone Area (GYA).
- As symbol of the American west, bison are an essential component of Yellowstone National Park because of their contribution to the biological, ecological, cultural, and aesthetic purposes of the park.

Figure 1

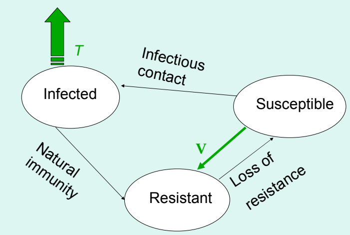
Yellowstone Region Map

- Brucellosis is thought to have been transmitted to different bison herds in the national parks of the GYA in the early 1900s (Godfroid, 2002). Some 30-40% of Bison in Yellowstone national park test seropositive for Brucella abortus (Cheville et al., 1998).

Objectives

Vaccination and test-and-slaughter have been applied to the brucellosis management, and there has been discussion that a combination of both could potentially eradicate the disease in the GYA .However, there is no study on how to allocate resources between the two actions. This paper investigates the optimal allocation of these two selective management options, in a bioeconomic framework, when there are both existence and recreational values for the wildlife host (bison) and when the host puts the livestock sector at risk.

Epidemiological model



- The model is based on Dobson and Meagher's (1996) single-species susceptible-infected-recovered (SIR) model.
- Each bison population consists of three sub-population: Susceptible, infected and resistant.
- We modify the model to account for vaccination (v) and test-and-slaughter (T) management choices.
- Disease Thresholds
  - Disease prevalence dissipates when the population is held below a threshold population level
  - Dobson and Meagher determine the disease threshold is small
  - We find the threshold endogenously depends on the controls V and T.

The bioeconomic model

- The manger of YNP's objective function is:

$$\underset{v,T}{Max} \quad SNB = \int_0^\infty [U(X_S + X_R) - c_1 v - c_2 T - \theta X_I] e^{-\rho} dt$$

$$st. \quad \dot{X}_S, \dot{X}_I, \dot{X}_R, \quad 0 < v, T < 1$$

Where $U(X_S + X_R)$ is the combination of existence and ecotourism value; $c_1$and c_2 is the cost of vaccination and test-and-slaughter. θ is the parameter for economic damage caused by infected bison.

- The changes of the three subpopulations are:

$$\dot{X}_S = G_S(X_S, X_I, X_R) - \kappa v X_S$$

$$\dot{X}_I = G_I(X_S, X_I, X_R) - T X_I$$

$$\dot{X}_R = G_R(X_S, X_I, X_R) + \kappa v X_S$$

- The current value Hamiltonian is:

$$H = U(X_S + X_R)\text{-}c_1 v\text{-}c_2 T\text{-}\theta\text{-} \ {}_I + \lambda_S \dot{X}_S + \lambda_I \dot{X}_I + \lambda_R \dot{X}_R$$

- We have constructed this as a linear control problem (i.e., linear in v and T), and examine the potential for double singular solution (i.e., singular for both v and T, so that neither control is constrained) and also partial singular solutions for v or T only (with the other control being constrained).

Preliminary Results

- Test-and-slaughter only removes the infected bison, reduces the force of infection within the population. The result is that this control increases the host density threshold: the disease can dissipate at a higher aggregate population level.
- Vaccination also increases the host-density threshold, but via a different mechanism as this control reduces the population at risk of infection. The controls are therefore substitutes for disease control.
- We find the double singular solution does not exist. A double singular solution involves the use of both controls, and so simultaneously it invests in reducing the force of infection and reducing the population at risk of infection. There are clearly tradeoffs involved: the benefits from reducing the force of infection are diminished when the at-risk population is reduced, and vice versa.
- Partial singular solutions occur as either v or T are bounded at 0 or 1. Feedback rules ($v(X_s, X_I, X_R)$ or $T(X_s, X_I, X_R)$) are solved for partial singular solution.

Conclusion

We develop a bioeconomic model to examine the socially optimal management of the Brucellosis disease in bison. We found that both vaccination and test-and-slaughter increase the host-density threshold, and therefore are substitutes for disease control. We need to consider trade off between risk of disease exposure and infection for disease management in valuable wildlife. Due to the complexity of the problem, numerical examples would be further needed to provide policy insights for brucellosis in bison in GYA.

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